Report of the 16th Electron Ion Collider Detector R&D Meeting

EIC Detector Advisory Committee

January 30, 2019

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Introduction

BNL, in association with Jefferson Laboratory and the DOE Office of Nuclear Physics, has established a generic detector R&D program to address the scientific requirements for measurements at a future Electron Ion Collider (EIC). The primary goals of this program are to develop detector technologies and detector concepts that are suited to experiments in an EIC environment, which will ensure that the full physics potential of an EIC can be harvested and that the resources for implementing these technologies are well established within the EIC user community.

The EIC Detector Advisory Committee meets twice a year, typically in January and in July. The current Committee members are: M. Demarteau (ANL/Chair), C. Haber (LBNL), P. Križan (Ljubljana University/J. Stefan Institute), I. Shipsey (Oxford University), R. Van Berg (U. Pennsylvania), J. Va'vra (SLAC) and G. Young (BNL). Not able to attend this meeting were Jerry Va'vra and Rick van Berg due to personal commitments. An invitation has been extended to Blair Ratcliff (SLAC) who will join the committee starting with the next meeting. During the January meeting progress reports are reviewed and feedback is provided to the proponents. During the July meeting both progress reports and new proposals are reviewed. Funding recommendations for continuation of existing and for new proposals are provided by the Advisory Committee to the program manager in advance of the fiscal year funding cycle.

At this meeting status reports were provided by ten funded projects. No report nor presentation was made by eRD15. The Committee met at Brookhaven National Laboratory on January 24 and 25, 2019 to hear the status reports and discuss the progress with the proponents. The committee would like to thank all the collaborations for their excellent presentations and status reports and BNL for its hospitality. The collaborations are to be commended for their progress. It is gratifying to see results being published in peer-reviewed journals, and all proponents are strongly encouraged to continue to publish their results.

General Remarks

With the release of the report of the National Academy of Sciences (NAS) on July 24 giving their strong support for the construction of an electron–ion collider (EIC), the Office of Nuclear Physics is expected to provide an informal mission need statement soon. The EIC User Group had a very fruitful visit to Congress on December 4, 2018. The next user meeting is planned for July 22-26, 2019 in Paris. The user Group currently has 849 members of 180 institutions, representing 30 countries.

Although this committee is advisory to the research program, we noted last time that the recommendations are not always being followed. The decision of the research groups to not follow the recommendations may be well justified but we request that, when there are clear deviations from the recommendations, they be justified both in the documentation and in the presentations at the meeting of the advisory committee. We were pleased to see that some collaborations addressed their response to our recommendations and we would like to encourage all collaborations to do so.

We note again that the EIC will most likely have CD-1 status within the next couple of years. This time scale is a near-perfect match for proposals to be submitted to the DOE sponsored Early Career Award Program (https://science.energy.gov/early-career/). We strongly encourage junior U.S. faculty to take advantage of this program. Given the high priority of the EIC within the Office of Nuclear Physics, proposals

with an instrumentation element that enables a key goal of the EIC physics program should be very well received. We also note the NSF Faculty Early Career Development (CAREER) Program that is available to the university community (https://www.nsf.gov/career). The next sections provide the committee's assessment on the progress of the eRD collaborations. All consortia are to be commended on the excellent work that is being carried out enabling the EIC science.

eRD1: EIC Calorimetry

O. Tsai, T. Horn and C. Woody reporting

Tungsten-fiber calorimeter development

The development of the W-powder SciFi matrix for use as an EM-Calorimeter has now reached maturity for deployment in sPHENIX (see Fig. 1). The development has led to working prototypes with good energy and position resolution, a choice of SiPMs for readout technology, all coupled with levels of radiation hardness that will result in a capable EM calorimeter for the barrel and hadron-going directions at an EIC. The collaboration is congratulated on this achievement. One could remark that the concepts developed to date are ready to be incorporated into the design for an EIC detector. Indeed, as noted above, a version is now being built for sPHENIX with some 300 towers already completed and a pre-production of over 4000 towers for sPHENIX expected to start later this Spring. The sPHENIX device now includes choices for the front-end electronics, light guides and reflectors, monitoring devices and cooling technology. That said, there is still room for improving readout performance, as noted by the eRD-1 group and also noted below.

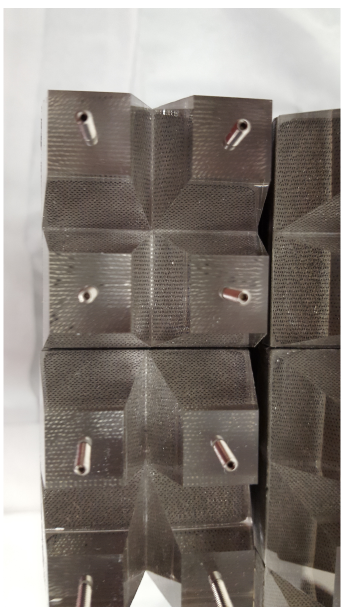
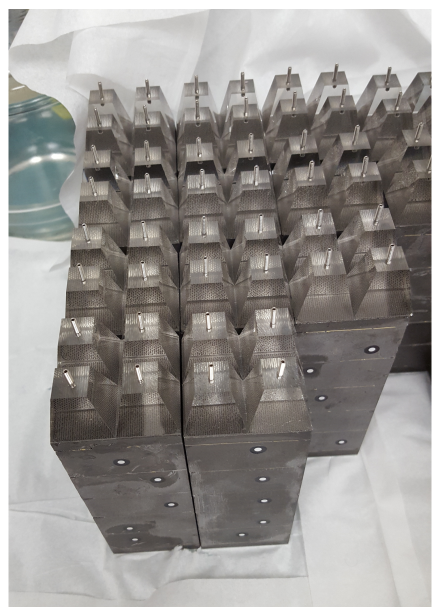

Fig. 1: Photograph of a set of completed calorimeter blocks of the Tungsten-powder/scintillating fiber calorimeter for the sPHENIX project with four extruded light guides mounted on top of each block (right). The photograph on the left shows the view from the top; the scintillating fiber matrix is clearly visible. The screw embedded in each light guide is to hold the circuit board with the SiPM readout.

The sPHENIX group reported further analysis of the FNAL test beam data of a final prototype, denoted v2.1, which is 2-D projective and addresses the issues noted earlier with light collection from the tower/block edges and the design of the light guides. The results address position dependence of the response of the blocks, the degree to which this may be removed via calibration, and limits on performance. A stochastic term of 13.3% is reported for the energy resolution for electrons, which

improves upon their earlier result and is most encouraging. A tremendous amount was learned about the benefits and limitations of W/SciFi calorimeter designs during this EIC R&D program and the design has now matured to a full-scale production effort for sPHENIX. The committee appreciates the tour of the calorimeter lab.

Results of a simulation study, made by ray-tracing, of light collection by the light guides were again presented and a response provided to various suggestions for improvement made in the report from the last meeting of the Committee. Present indications are that increasing the area covered by the SiPMs may be the most fruitful avenue for improvement; this could take advantage of new larger 6mm *x* 6mm SiPMs, and indeed a prototype adopting the new form factor is being developed by the group. The Committee repeats the remark that sPHENIX can accept this loss of resolution due to non-uniform response but a new EIC detector should not. It would also be of interest to study the timing performance which could be achieved with SiPM readout. Proposals on these subjects might be the focus of future work.

The collaboration reported at the last meeting results on their continued measurement of the effects of radiation exposure to the long-term performance of SiPMs. A set of measurements in the STAR interaction region, near the DX dipole, was again presented and reviewed, and the proposers noted that a report is being prepared. New information on thermal response was presented. Results of calculated neutron fluence to be expected after 10 fb^{-1} running at an EIC in a reference detector (BEAST) were reported and noted to be quite encouraging regarding the expected dose at an EIC. The proposers presented analyses placing these in the context of expected radiation levels at an EIC.

The collaboration also presented new results on radiation tolerance of a new series of SiPMs available from HPK having deeper trenches around the active cells. Early results for the post-radiation exposure response indicate an order of magnitude less loss of response for these new diodes compared to those studied and deployed to date, which is most encouraging for use at an EIC. The Committee again encourages continued analysis and dissemination of these results. As consequence, this study points to the need for a good monitoring system for a W-SciFi calorimeter, more so given the SiPM aging behavior. The design of this could be a subject of future development.

The Committee congratulates the group on the completion of this particular line of R&D and looks forward to possible future new proposals addressing issues noted above.

HCAL Studies

At the last meeting a new proposal was made to examine the timing of the signals from a hadronic calorimeter and compare the time-integral of the early-time component of the signal versus the total time integral, and use that as a discriminant between electrons and hadrons. The power of this may well depend on the amount of neutron generation during the hadron shower. The proponents argue to test this concept using a hadron calorimeter in a mixed beam of electrons and hadrons such as is available at the FNAL test beam. The calorimeter would need to be large enough to guarantee transverse and longitudinal containment of the hadronic showers; the Zero Degree Calorimeters built for various fixed-target and collider experiments would be useful devices to test, if they are available. The proponents suggest making test structures using iron plates and then later lead plates, with scintillating-tile and (possibly) WLS plate readout. The Committee found this suggestion intriguing and encourages its pursuit and recommended some economy in re-using of existing materials and optical readout systems and

electronics to accomplish these tests.

The collaboration reported that this is work in progress but did not report further on the timing aspect. The collaboration did report on Monte Carlo studies of longitudinal and transverse hadronic shower containment as a function of device size, as part of a study in part to determine the scale of a device needed to ensure that shower leakage did not mask resolution improvements from the timing method noted above. The Committee looks forward to a full report at the next meeting.

Shashlik Concept

The Committee takes note of the shashlik development at UTFSM using W-Cu plates to realize a compact shashlik EM-Calorimeter. The construction of enough blocks, which are read out as 2x2 towers, to form a 3x3, 5x5 or similar tower matrix, was encouraged. A first block comprising a 2x2 set of towers was constructed and readied for readout studies. The goal is to measure performance in a test beam, and then compare its performance to the old PHENIX shashlik EMCal towers, which can be reconfigured to read out the individual WLS fibers, as proposed by the group.

Re-use of existing readout sensors and electronics to do this economically is encouraged. Whether these are PMTs or SiPMs or other devices seems less important than understanding the performance of the device as an EM-Calorimeter.

The Committee commends the progress to date and looks forward to further reports. The collaboration noted they also plan to obtain one or more of the now-surplus PHENIX lead-scintillator-WLS shashlik calorimeters for testing, including in-beam.

Crystal calorimeter development

Efforts are ongoing to characterize lead-tungstate crystals from CRYTUR and SICCAS. The need to qualify a vendor in order to be able to propose a high-resolution scintillating crystal EMCal for the EIC is noted. The Committee also takes note of the recent acquisition of several hundred crystals from SICCAS and another hundred or so from CRYTUR. There remain concerns about materials control and purity, as well as crystal handling at SICCAS, which is puzzling. The issue with CRYTUR seems to be more of factory capacity, which could well be resolved should a large order be needed. The sources of new raw material for CRYTUR and control of its purity appear to be issues going forward. The uniformity results presented for CRYTUR crystals are particularly encouraging.

The group has established required values for light yield, uniformity and radiation resistance for such a crystal-based EMCal at the EIC and is actively pursuing measurements to determine if presently-produced crystals meet them. The measured results are now at a level to provide useful feedback to potential vendors. The effort for the EIC benefits from the work being done for the Neutral Photon Spectrometer at JLab by several of the same people.

The collaboration has assembled a 12x12 array of $PbWO_4$ crystals, each 2.05cm x 2.05cm x 20 cm in size, and deployed it in Hall D at JLab, where tagged photons of 1-10 GeV are available. An energy resolution of 2% was reported for 4.2 GeV electrons and 1.4 - 1.6% for 10 GeV photons.

Recommendation:
The Committee looks forward to further systematic results on energy and position resolution and takes note of the collaboration's pro-active efforts here, and is looking forward to future reports and their long-term research plan.

Scintillating Glasses

The collaboration reported first results on radiation hardness (up to 1000 Gy), transmission versus wavelength, and fluorescent light yield for 160 nm excitation, for samples of scintillating glasses. Large fluorescence light yields relative to $PbWO_4$ were noted. Significant improvements in controlling bubble density in samples were shown. This was most encouraging.

These are initial results based on their study of various scintillating glasses with an eye to improving their basic characteristics with regard to impurities, defects, density and average atomic number, and thus Molière radius and radiation length. Such glasses are similar to lead-glass in many properties but exhibit up to 100x the light yield per GeV. They offer a path to an inexpensive high-resolution EM-Calorimeter, which could be of interest at an EIC in the central and forward, if not necessarily the far-forward, regions. Such glasses have been made with various compositions but typically have been limited to small samples of 1cm scale due to difficulties with scaling up the production while maintaining the needed purity. The VSL at CUA offers the facilities and expertise to pursue this work and thus offers an interesting opportunity for progress.

Recommendation:

The Committee enthusiastically endorses the continuation of this new effort and encourages the group to elaborate their research plans with well-defined milestones. The Committee looks forward to further reports at future meetings.

eRD6: Tracking Consortium for the EIC

B. Azmoun reporting

The eRD3 and eRD6 collaborations have merged and provided a single report on a broad range of efforts on Micro-Pattern Gas Detectors (MPGDs) for tracking and particle identification, which covered the activities at each collaborating institute. The Brookhaven effort focused on the testing of a new 4-layer GEM TPC with optimized zigzag readout. A detailed analysis of the test beam data has been carried out and the zigzag readout seems to be close to demonstrating fully satisfactory performance for EIC use. Further optimization of the zigzag readout is planned, which the committee encourages. The cosmic ray test stand at BNL has been completed and readout of the 4-layer GEM, with the SAMPA and DREAM chips, is under development. Testing of Micromegas and μRWELL foils with the zigzag readout is also planned. A new high-intensity x-ray scanning facility has been constructed, which should provide a powerful diagnostics tool for MPGD development.

FIT has continued to work on the refurbished low-mass prototype GEM forward tracking module and to characterize its performance. Hit residuals were determined for tracks through the forward low-mass GEM chambers to study how the reduction of material affects the spread of track position due to multiple scattering. No noticeable difference was reported, though a full study of the physics impact was not completed.

Good progress was reported on the studies of the photosensitive thick GEM planes with resistive Micromegas at Trieste. A very successful test beam was concluded at CERN with very encouraging results, with clear demonstration of the embedded photosensitive material for particle ID. The coupling of a Nano-Diamond photon-detector to the MPGD led to unexpected increase in gain, which is not understood.

Stony Brook has carried out a detailed study of the IBF in the context of an sPHENIX TPC to derive the hit resolutions through simulations. They also initiated a study into the use of optical materials to tailor the Cherenkov effect in a way that would greatly improve the particle ID reach. COMSOL-based simulation studies have started and they are able to reproduce various published results. Attempts to invite experts in the field have been unsuccessful.

The GEM activities at Temple University in the framework of RD3 are being phased out. The committee is very pleased to hear that the infrastructure at Temple for MPGD R&D will be maintained and support will be provided to users who want to make use of the facilities. Focus has now shifted to simulation studies of the performance of μRWELLS operating in μTPC-mode in the central rapidity region. The efforts at UVA focused on the study of large-area triple GEM trackers with a focus on low-mass, low-cost support frames and UV readout. The chamber was tested in the Fermilab test beam. Analysis of the data led to the discovery of many shorted strips, the cause of which is still under investigation. The data analysis is only mildly affected. A small μRWELL chamber with 2D readout was also tested in the test beam, which shows very promising results for the position resolution.

The eRD6 consortium presents its results based on what was done at each institution in the consortium. This approach has not led to illustrating the coherence, synergies and collaborative efforts within the consortium. One of the goals of being a consortium is to share techniques, experiences, equipment and

even interchange personnel to maximize the efficiency of the R&D efforts. The last reports and presentations could improve on better articulating the added value of being a consortium.

Recommendation:

The committee was very pleased with the many encouraging test beam results shown and strongly encourages completion of the data analysis and publication in peer reviewed journals. The collaboration is encouraged to continue developing the TPC readout with different electronics and studying the Micromegas and µRWELL with zigzag readout in a planar detector configuration. It is recommended that the full simulation studies, including the track reconstruction and determination of the impact point on the RICH entrance window of low-mass GEM trackers with chromium foils be completed and its physics impact be determined to close on the issue of the value of chromium foils. The potential payoff of the use of meta-materials is big and the group is encouraged to keep up the efforts to engage experts in the field for possible applications to an EIC particle ID detector.

Further studies of a cylindrical µRWell barrel layer to act as a fast-tracking layer in a non-TPC EIC detector is strongly encouraged. Efforts between the various institutions should be coordinated.

The consortium is encouraged to revisit their reporting and find a mechanism that gives prominence to the shared experiences and the added value for being a consortium.

eRD14: Integrated Particle Identification for a Future EIC

P. Nadel-Turonski reporting

The committee finds that the presented results present a very good step forward.

Comments and Recommendations:

dRICH:

The interaction between the aerogel and the C_2F_6 gas should be investigated with high priority, as well as the scintillation properties of the gas, which could represent a real limitation of the proposed RICH. Tests with the prototype under preparation are strongly encouraged. Although such a prototype would be useful to study a number of questions, the committee strongly discourages going into such a large effort with haste. We note, for example, that the SiPM option is uncertain until it can be shown that such detectors can be used in an EIC environment. This requires a separate study of various types of SiPMs. That alone is a big effort and is basically a bench test. These devices could later be used on the prototype. A prototype should only be built when the collaboration is fairly sure about its choices and then verify them with a prototype.

mRICH:

The committee is pleased that the radiation hardness study has shown that the acrylic Fresnel lens is reasonably radiation hard, and that beam test results clearly indicate that the SiPM arrays would work well for mRICH in test beam conditions.

DIRC:

The committee acknowledges the excellent results from simulations and the beam test of the Panda prototype at CERN, as well as good progress in radiation hardness measurements of the lens materials. However, for the two material candidates, sapphire and PbF_2, it remains to be shown that they can indeed be used for manufacturing.

Photo-Sensors:

- SiPMs:
  Single photon detection capabilities of the irradiated sensors has to be investigated. The tests indicate that SiPM cooling may be very important, although it was not presented quantitatively in terms of a rate as function of temperature. However, we should mention that cooling at -30 ^{o}C in a real experiment represents a serious challenge. We also encourage the group to consult with the eRD-1 EMCal collaborators on SiPMs and radiation damage in the area of the dRICH.
- Tests of commercial MCPs in high magnetic field:
  The results should be compared to previous studies in the framework of the Panda collaboration. The committee also notes that operating at very high gains (10^6) should be avoided to reduce the photocathode aging due to feed-back photons.
- LAPPD:
  The results of device tests are encouraging. The σ(TTS) of about 20ps of the new tube with 10 um pores is surprisingly good; a better understanding, however, is needed, including a simulation of the response. The results shown had a large tail in the timing distribution for the 20 μm pore size

tube. This tail was attributed to backscattering. The new tube has a 10 μm pore size MCP and a smaller photocathode-to-MCP spacing compared to the tube with 20 μm pores. Qualitatively, the smaller spacing contributes to a suppressed backscattering signal, and the smaller pore size MCP results in better timing. Small spacing does eliminate the tail, as has been verified in earlier measurements. A more quantitative understanding, however, using simulations is much desired.

- Running these tubes at a gain of ~$3x10^6$ seems excessive and may lead to large ion feedback rates. The result of tests in magnetic fields show a drop of gain by a factor of 10 by going from 0.2T to 1.3T, considerably worse than what has been achieved with Photonis XP85112 10 micron hole MCP-PMT. The committee is also worried about a potential manpower issue for the LAPPD effort. For the next report, the committee requests a map of the magnetic field in the EIC detectors to understand its possible implications in running these tubes.
- The committee would like to note that, in general, to ensure a single photoelectron signal, the probability to have an event should be well below 10%.

Electronics:

The new multi-pixel detectors require highly pixilated electronics to verify that a given detector concept works, and this is required already at the test beam stage. The committee therefore fully supports the development of this electronics. However, the committee also notes that each chosen electronics path takes a lot of energy to verify its detailed performance with each of the sensors. Above, we recommended consultation with the eRD1 group on radiation damage but we want to stress that RICH detector SiPM tests must be done with electronics which has appropriate threshold sensitivity, which is single pe.

eRD15: Compton Polarimetry

No report

Silicon Tracking General Remarks

The Committee endorses the silicon efforts of the eRD16 and eRD18 collaborations and congratulates the two teams on their progress and increasing collaboration. As stated earlier, we see an obvious synergy, complementarity, and overlap, which makes an eventual merging very natural. We support the idea of a tracking workshop, in the near future and would be pleased to be kept informed. We support the use of common tools and hope they can be rationalized between the users, with consistent results. Of great value would be the convergence on a clear specification for the tracker and the electronics, in particular around the need for, or not, of timing, perhaps at the July 2019 review.

eRD16: Forward Silicon Tracking

E. Sichtermann reporting

At the time of the July 2018 review a set of findings, comments, and recommendations were given to the project. We encourage the teams to review those. We won't reproduce the findings, nor comments here, other than to state any new ones. We will refer to the recommendations.

The committee notes continued progress and collaboration with eRD18 and is encouraged by the idea of a tracking workshop this summer. We hope that the scope and goals of this workshop will be increasingly well defined and look forward to being kept abreast of this as it develops.

The recommendations from July 2018 were as follows:

- Please consider adopting a more uniform reporting template (like eRD18 and others) consisting of the "What was proposed/achieved, not achieved, was is planned etc." form.
- The case for, and physics-use of, a fast timing layer should be better motivated and described in future presentations.

Findings

- While none-the-less coherent and readable, we note that the requested format was not yet adopted.
- The team is using two simulation tools, a fast simulation derived from tools developed for ILC, and an EIC based full GEANT tool, EICroot.
- Results comparing the two are consistent except at low momentum where it is stated that multiple scattering has a larger effect in the fast simulation. This is shown in Figures 2 and 3.
- Figure 3 is compared to the EICroot results of eRD18 (their Figure 4).
- Statements in favor of, or justifications for, a timing layer are weak.
- The addition of a timing layer would result in little to no degradation to the tracker momentum resolution.
- Results were shown on tracker layouts with varying disc diameter and the barrel to disc transition region was studied.
- At the level of the present simulation tools, large variations in resolution were noted across the barrel to disc transition, in some cases.

- An increasing effort on hardware aspects – sensors, low-mass conductors, and cooling is planned for the upcoming period.
- A multi-campus UC grant to support further work was recently awarded.

Comments

- The low-momentum discrepancies between EICroot and LDT are hard to understand. Are they even in the expected direction?
- In the comparison of momentum resolution, the overall level is clearly different between even EICroot as used by eRD16 and eRD18, for similar configurations. This is hard to understand.
- Non-uniform momentum resolution across a transition region, can easily become a point of major concern, but should be carefully assessed for its actual importance. It can drive the design of the tracker in desperate directions.
- It would be good to arrive at a consistent set of specifications with respect to eRD18, particularly in the realm of timing.

Recommendations

- Continue to consider adopting the suggested report format.
- Reconcile the differences in resolution between the various simulation tools and between eRD16 and eRD18.
- Clarify with eRD18 the role and necessity of a timing layer, particularly since they propose to expend EIC R&D resources on electronic design for it.
- Pursue with eRD18 a broader tracking workshop.

eRD17: EIC Calorimetry: Beagle

M. Baker reporting

BeAGLE is a generator to describe eA collisions for the EIC. The proponents use real data from E665 to validate the physics model. The code is being used for physics-driven refinements of detector requirements, particularly in the forward region at both BNL and JLab and is essential in establishing EIC detector requirements

The proponents again submitted a report clearly delineating the progress made and the plan for future work. The proponents have achieved many of the goals as originally foreseen, and as foreseen for the last funding period, explicitly task 19b (release of the beta version of BeAGLE/RAPGAP), task 21 (update the Fermi momentum for e+D) and task 22 (completing BeAGLE documentation). Where the schedule for some tasks has slipped it is because they have taken on more urgent goals in response to input from the theory community. It is now clear that an understanding of light nuclei, as well as heavy nuclei will be necessary and they have made progress modelling deuteron targets (task 23 putting e+D on mass-shell). They are also working on the implementation of short-range correlations between the struck nucleon and the spectator nucleons supported by a JLAB LDRD. This contributes to efficient tagging of spectators and identification of events. Despite these new work areas, they are still intending to complete the whole original package by the end of FY2020 if funding allows.

The proponents are responsive to committee recommendations and suggestions; in particular, they addressed the committee recommendations made in July as follows:

> *Spreading BeAGLE expertise more widely*: as well as increasing awareness of the project by attendance at workshops and conferences, they have taken the very important step of clear documentation of the program on GIT such that anyone can now run it.
>
> *Accelerating the work*: they propose to retain the student Chang by paying for her accommodation, should funds be granted. This request is supported by the committee.
>
> *Addressing continuity*: There is a growing base of developers and this is welcomed by the committee. Baker is available at 25% for eRD17. The funding for this both now and in the future is essential.

eRD18: Precision Central Silicon Tracking & Vertexing for the EIC

P. Jones reporting

At the time of the July 2018 review a set of findings, comments, and recommendations were given to the project. We encourage the teams to review those. We won't reproduce the findings, nor comments here, other than to state any new ones. We will refer to the recommendations.

The committee notes continued progress and collaboration with eRD16 and is encouraged by the idea of a tracking workshop this summer. We hope that the scope and goals of this workshop will be increasingly well defined and look forward to being kept abreast of this as it develops.

The recommendations from July 2018 were as follows:

- Considering the general issue of underspending, confirm that past and new funds allocated for an ASIC designer are being spent as proposed and report back to the committee in 6 months
- The case for, and physics-use of, a fast timing layer should be better motivated and described in future presentations.

Findings

- Work is planned for the RAL engineering team, but is mainly still pending, therefore, largely, the allocated funds have not yet been spent.
- There still remains some difference between eRD18 and eRD16 on the possible role or value of the timing layer.
- The presumptive outer timing layer would cause little or no degradation to the momentum resolution of the central tracker.
- Simulations have been carried out using an EICroot framework.
- Simulations have been extended into the disc region.
- eRD18 and eRD16 disagree on the shape of the momentum resolution versus momentum, below 5 GeV/c, and the overall levels are different as well.
- Results from EICroot alone differ between eRD18 and eRD16.
- Results were shown on signal amplitude from various TJ test structures for different pixel geometries and operating conditions.
- Signal amplitude varies with HV, beyond full depletion.
- Discussions are underway with RAL ASIC designers towards sensor design and architecture, again with a focus on the role of timing.
- Going forward the plan is to complete the characterization studies, clarify the observed dependencies, and reach a fuller design specification with RAL, to be reported at the July 2019 meeting.

Recommendations

- Reconcile the differences in resolution between the various simulation tools and between eRD16 and eRD18
- Further advance and clarify the characterization studies underway for the TJ structures.

- Clarify with eRD16 the role and necessity of a timing layer, particularly since you propose to expend EIC R&D resources on electronic design for it. It would be great to see a more definitive and coherent discussion of this in July.
- Carry out the proposed design plan, which has been funded, at RAL.
- Pursue with eRD16 a broader tracking workshop.

eRD20: Software Development

Markus Diefenthaler reporting

The EIC Software Consortium (ESC) noted that for the last 30 years or so the computing model for Nuclear Physics has not changed and that the community needs to prepare for adapting new computing paradigms, especially in the era of exascale computing. They have organized a workshop on AI/ML last November for the EIC community. A Software Working Group has now been established within the EIC User Group, which is expected to build on the progress made within the eRD20 Software Consortium. Two key members of eRD20 are the conveners of the Users Software group, though one of them has now left for a position in industry. The goal for the year has been to reach out to the EIC community and bring existing software to the end users and provide the community with documentation. A collaboration with MCNet has been established and work on providing a framework for event generators, including radiative effects, has started. A workshop is planned at DESY in February. The ESC has continued to work on common interfaces (geometry, file formats, tracking, etc.) and work on an event data model based on Google's protocol buffers is proposed.

The committee is very pleased to hear that the consortium plans outreach activities to help ease entry of the user community into detailed simulation efforts. It surprised the committee that no events are planned at the next EIC user meeting, where a large fraction of the community can be reached. The feedback from the user community indicates that there is a keen desire to have access to reliable and easy simulation and reconstruction frameworks. It seems that there remains a threshold for users to quickly engage in Monte Carlo simulations to carry out an end-to-end evaluation of various detector designs and study the EIC physics performance for different detector configurations.

Recommendation:

The EIC science community will not drive the exascale computing effort, nor will it drive AI or ML advances. The committee encourages the ESC to follow the developments in these areas while keeping a realistic attitude. The effort on providing common interfaces is strongly supported and the ESC is strongly encouraged to interact with the user community at the next EIC user meeting. It is suggested that daily tutorials are provided with documentation at the next EIC Users Meeting that will enable participants to be self-sufficient in their simulation and reconstruction efforts.

eRD21: Background Studies

Charles Hyde reporting

The proponents of eRD21 continue to progress well. Among the achievements are: initial simulations of beam-gas interactions in the central vacuum chamber; progress on synchrotron radiation simulations from the final focus quadrupoles to the IP and SVT, and development of a vacuum pressure model with interface of CAD to Molflow+ and Synrad. Of particular significance, collaboration is underway between the different teams: detector, machine, IR design, and vacuum for JLEIC and eRHIC. The development of Python tools to convert MAD-X geometry and fields to GEANT4, aid the iterative design of the accelerator lattice with engineering changes.

The committee previously recommended to determine the thermal neutron flux; this work has started, as noted in the future activities section of the proposal, and some very preliminary results were shown in the presentation. Estimating the thermal neutron flux is a high priority and the committee is keen to see a detailed study presented at its next meeting.

The committee previously also recommended an analytic estimate of beam-beam interactions, which was not mentioned in this progress report nor in the presentation. Parasitic collisions between incoming and outgoing beams may be suppressed or even excluded by the large crossing angle of 50 mrad of JLEIC. The committee reiterates its recommendation to check any beam-beam overlap based on the bunch dimensions and timing and expects to learn of the results at its next meeting. The case for beam-beam interactions at eRHIC, which has a crossing angle about half that of JLEIC, should also be studied at some future time.

The planned work on synchrotron radiation focusing on beam tails is timely and appropriate as the recent experience of the superKEKB accelerator and the Belle II detector have shown. Beam tail distributions have become much more important in new high current, frequent-injection accelerators. The committee is eager to see the results of these studies in July.

The proponents of eRD21 also continue to progress well with studies of beam-induced backgrounds (BIB), focusing currently on local interactions of the proton beam with residual gas within the central vacuum chamber, which is encapsulated by the silicon vertex tracker (SVT). This central beam pipe is modeled as a beryllium cylinder of length 198 cm and 3.2 cm diameter containing hydrogen. Although this local model serves for an initial estimate of the relationship between background rate and vacuum pressures, it will likely underestimate the SVT occupancy levels for several reasons, which are recognized by the proponents and will be the subject of the next phase of the work. It is possible the upstream generation of beam-gas may dominate. [ATLAS LHC studies show that BIB reaching the Pixel detector and larger radii detectors originate primarily from beam-gas interactions significantly upstream of the IP (>20m), due to the shallow opening angle of showers induced by beam-gas interactions. These beam-gas showers typically traverse the silicon tracker almost parallel to the beam pipe, creating long trails of pixel hits in the barrel silicon layers. Dependent on the SVT topology at an EIC, this may significantly increase the occupancy per event, compared to hard beam-gas interactions generating high p_T tracks from within a central 2m long vacuum chamber. This may need particular study for eRHIC, given that the straight sections adjacent to the Interaction Point are 100m long in that case.] BIB also arises from normal off-momentum beam halo cleaning losses on the collimators, which generates showers that can reach the detector, and global beam-gas elastic scattering all around the accelerator can induce losses on

collimators and subsequent showers reaching the detector. The choice to simulate hydrogen could be complemented by investigating other gas species likely to be present in the vacuum system such as CH_4, CO, CO_2. (LHC simulations use nitrogen as an approximation between carbon and oxygen.) The committee is eager to see comprehensive results of the beam induced backgrounds in the submitted report and presentation in July.

eRD22: GEM-based Transition Radiation Detector

Yulia Furletova reporting

Comments and recommendations:

eRD22 has built a standard Cu-GEM-TRD/TRT prototype, which is currently under test. A new Cr-GEM-TRD/TRT prototype is under assembly and will be tested in a next test beam run. These chambers differ from the general GEM trackers through the use of Xe as an x-ray absorbing heavy gas, an increased drift region for better x-ray absorption and the addition of a radiator in front of the chamber for the generation of transition radiation. GEANT simulations were carried out and the prototype tested in Hall D at JLab. e/π rejection was studied using machine learning techniques based on Monte Carlo simulations. Rejection factors of about 15 were relatively easily obtained at 90% electron efficiency. Tests with different gases and gas mixtures is proposed.

The committee finds the presented results very interesting. The results from the prototype indicate that a fleece radiator is preferred to the regular foils. The optimization studies resulted in a new set of detector parameters. However, the committee is not convinced that the advantage of Cr GEM foils was demonstrated; because of possible issues that this foil type could bring in running the device, we need results from a prototype test and a demonstration of a clear impact on physics in the simulation before drawing any conclusions.

eRD23: Streaming Readout

J. Bernauer reporting

The collaboration reported on a series of meetings held with interested parties concerning new detector readout and data-collection topologies and expanded upon their concept as first discussed at the prior meeting of the Committee. Several examples were presented of how a shift to streaming readout might be beneficial for, and deployed in several ongoing and envisioned experiments.

It is requested that the collaboration prepare for the next meeting a Glossary of terms to ensure agreement upon terminology for: triggered readout, streaming readout, as well as other terms as they should choose to include. Some remarks on how one would classify conventional Level-1, Level-2 and High-Level triggering approaches from their perspective would be welcome.

An interesting exercise would be to put forth a model detector, with choices about technology, channel count, sampling rate and precision for each type detector included, and deduce raw and (e.g.) zero-suppressed data rates and volumes. To be specific, the data rates and volumes resulting from an EIC run at nominal luminosity of 10^{34} cm^{-2} s^{-1} resulting in 100 fb^{-1} examined could be estimated. Readout topology would then be sketched in for a triggered vs. a streaming approach, and a rough cost estimated using current technology. The readout for ongoing experiments with triggered and streaming front-ends could be used as a reference. For the streaming approach, some discussion of data volumes and how they would be moved using, for example, currently available optical technology, including serializers and de-serializers, with commercially available engines such as FPGAs, and how one would store the results, would be useful.

A key feature of currently implemented versions of streaming readout is that it allows detection of channels that otherwise would be inaccessible. Streaming readout enables the reconstruction of difficult event signatures that would not be possible using a conventional triggering scheme. Clear examples indicating how streaming readout would benefit an EIC detector would be helpful.

Further commentary as the collaboration chooses, on topics such as a global time stamps, on event building vs. cataloging and retrieval, and other topics such as storage and the needed scale of data centers, and whether they would be localized or distributed, would all be welcome. Comments on software development needed are also most relevant, both for recording and for replay/analysis.

The Committee looks forward to further elaboration of this approach including merits and demerits. Projections of future technical developments in the field are welcome, but the analysis above should take note of current technical status that might be deployed.